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DEVELOPMENT OF HIGH STRENGTH FLY ASH/PORTLAND CEMENT CONCRETE FOR PRECAST INDUSTRY

PHASE II

by

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of

Canada Cement Lafarge Limited

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DEVELOPMENT OF HIGH-STRENGTH FLY ASH/PORTLAND CEMENT CONCRETE FOR PRECAST INDUSTRY

PHASE II

CONTINUATION EXTENDING CURING REGIME

by

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ABSTRACT

Phase I of this investigation showed that incorporating up to 40% fly ash did not significantly increase the one-day compressive strength of concrete when cured at room temperature. At this temperature, the fly ash reacts much too slowly and only begins to improve the overall properties of concrete at the later age of 28 days.

This paper reports results of Phase II of this study in which heat curing of the concrete as is commonly practiced by the precast industry was investigated. We repeated the exact same mix designs of phase I and cured them at 40°C, 55°C and 70°C. The heat curing cycle consisted of two hours preset followed by 20 hours heat curing and two hours cooling at room temperature.

The results show that heat curing of fly ash/Portland cement concrete catalyses the fly ash reaction and increases the early compressive strength by as much as 50%. Therefore, fly ash could be a promising supplementary cementitious material for the precast industry.

Backed by these encouraging results, we recommend to further this investigation to determine the optimum heat curing cycle and define the most appropriate preset time, heat curing temperature and cycle duration. We also recommend to include other sources of fly ash in order to expand the scope of this study to other regions of Canada.

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INTRODUCTION

The use of mineral by-products in concrete can contribute to the conservation of both energy and resources.

One such material is fly ash, a by-product from the combustion of pulverised coal in thermal power stations.

Fly ash is being incorporated increasingly in concrete at ready-mix plants for cast in place construction, however, its use in precast concrete to replace cement or fine aggregate is relatively unknown in Canada.

In 1981, CANMET reported investigation on the «Development of High Strength Concrete incorporating a large percentage of fly ash and superplasticizers» and indicated possible uses of fly ash in precast concrete industry.

Phase I of this investigation was a follow-up of the study reported by CANMET in 1981. The results show that incorporating up to 40% fly ash from an Alberta source did not significantly increase the 1 day concrete compressive strengths when cured at room temperature. At this temperature, the fly ash reacts much too slowly and begins to improve the overall properties of concrete at the later age of 28 days.

In order to accelerate the anticipated benefits of fly ash on the early strengths of concrete, we pursue this study including heat curing of the concrete as is commonly practiced by the precast industry. In this manner, we hope to activate the fly ash reaction thereby contributing more significantly to the concrete compressive strength at 24 hours and justify the useful application of this low energy by-product in the precast industry.

SCOPE OF INVESTIGATION

The test program consisted of an evaluation of high-strength air-entrained concrete containing type 30 Portland cement and four fly ash contents (0%, 20%, 30% and 40% by weight of cement) in combination with two commercially available admixtures (a super-plasticizer and an air entraining agent). The concrete was heat cured in order to activate the beneficial effect of incorporating fly ash. We studied one heat curing sequence under three different temperatures, 40, 55 and 70°C.

The following series of concrete were made.

i) Program X

To determine the mechanical properties of concrete made with a water-to-cement ratio of 0.45 with or without fly ash.

ii) Program Y

To determine the mechanical properties of concrete made with a water-to-cement ratio of 0.40 with or without fly ash.

iii) Program Z

To determine the mechanical properties of concrete made with a water-to-cement ratio of 0.35 with or without fly ash.

MATERIALS USED

The materials used are from the same sources as in Phase I, their description follows.

Cement and fly ash

CSA type 30 high early strength cement (ASTM type 3) and a Western Canada fly ash meeting the requirements of ASTM standard C 618 for a class C fly ash were used. The physical properties and chemical analysis of the cement and fly ash are given in tables 1 and 2 respectively.

Aggregates

Graded crushed limestone of 20 mm maximum size was used as coarse aggregate and natural sand was used as the fine aggregate. The relative densities of both the coarse and fine aggregate was 2.70, the absorption values were respectively 0.5 and 0.7 (CSA Can 3 - A23.2; 6A and 12A).

Air entraining agent

The air entraining agent used in the concrete mixes was a sulphonated hydrocarbon type.

Superplasticizer

A superplasticizer sulphonated naphtalene formaldehyde condensate type was used in the concrete mixes. They are usually available as 42% aqueous solution with a density of 1,20 and are dark brown. The chloride content is negligible.

CONCRETE MIXES

The mix series A and B of Phase I were cured at 20 ± 2°C. In this second phase, we repeated the exact same mix designs and cured the concrete at three different temperatures. The overall project outline is presented in Table 3.

The type 30 Portland cement content was kept constant at 370 kg/m³. The fly ash replaced part of the fine aggregate. The slump was maintained the same throughout the project by the use of a super-plasticizer while the air content was controlled through the use of an air entraining agent.

The mixing procedure was as follows: the coarse and fine aggregate, the cement, the fly ash (where used) and the water together with the air-entraining agent were placed in a pan mixer of 0.06 m³ capacity and first mixed for one minute. The mixing was continued and the superplasticizer (where used) was added during the next 2 ½ minutes.

The properties of the fresh concrete, i.e. slump, density and air content were determined immediately after mixing, (Table 4). The concrete one day density was measured after demoulding.

PREPARATION AND CASTING OF SPECIMENS

Altogether, there were 36 different concrete mixes, with or without fly ash. Each mix series consisted of two identical batches mixed consecutively. Test cylinders, 150 x 300 mm (6 x 12 in.) and prisms 75 x 75 x 350 mm (3 x 3 x 14 in.) were cast. The details of the specimens cast are given in Table 5. The cylinder specimens were compacted by the standard rodding procedure and cast in plastic moulds. The prisms were compacted by vibration and cast in steel moulds.

All the specimens were covered with a plastic plate to prevent moisture loss. Heat curing was provided in a forced convection oven. The curing regime was as follows:

- preset period of 2 ± 1/4 hours;
- heat curing for 20 hours;
- cooling at room temperature for an additional 2 hours.

The cylinders were then demoulded and transferred to a standard curing room until required for testing.

TESTING OF SPECIMENS

The cylinder and prism specimens were tested in accordance with the schedule shown in Table 5. The test cylinders for compressive strength and for modulus of elasticity were capped with a sulphur capping compound on both ends and tested in accordance with CAN 3 - A23.2 - 9C (ASTM C39) for compressive strength and ASTM C469 to determine the chord modulus of elasticity. The test cylinders for splitting tensile strength were tested according to CAN3 - A23.2 - 13C (ASTM C496). The test prisms for flexural strength were tested according to CAN3 - A23.2 - 8C (ASTM C78) using simple beam with third-point loading.

TEST RESULTS

The strength test results and modulus of elasticity are presented in Table 6 for each batch. They are further sorted by water-to-cement ratio and fly ash content in Tables 7 and 8. Plots of the compressive strength versus the fly ash content are shown at 1 and 28 days in figures 1 and 2 respectively.

DISCUSSION OF TEST RESULTS

Mix Proportionning

Fly ash was introduced in additions of 20%, 30% and 40% by weight of cement to the reference mixes to compare the concrete properties of mixes with and without fly ash at three different W/C ratios which were 0.45, 0.40 and 0.35. No difficulties were encountered in Phase II to reproduce the exact same mix designs of those in Phase I.

Fresh Concrete

The workability of the mixes was satisfactory. The dosages of super-plasticizer and air entraining agent were kept about the same as in Phase I unless minor changes were needed to adjust the workability and air content.

Heat Curing

The results were obtained in Phase I with the concrete cured at room temperature. In Phase II, we heat cured concrete of the same mix designs at 40°C, 55°C and 70°C. Only one heat curing cycle was adopted: 2 hours preset and 20 hours heat curing followed by two hours of cooling at room temperature. The longest heat curing period possible within a 24 hour cycle was chosen to make sure we would activate the fly ash reaction in concrete.

Compressive Strength

Early compressive strength gains from both heat curing and fly ash addition can be seen in figure 1. As the curing temperature increases, the concretes containing fly ash produce higher strengths than the reference concretes. Also, for a given heat curing temperature, compressive strengths increase as the fly ash content increases. Net increases as high as 40% to 50% are obtained through heat curing and fly ash addition.

As expected, the later 28-days compressive strength of heat cured concrete is lower than the compressive strength of the reference concrete as can be seen in figure 2. The net decrease is approximately 8%.

Modulus of elasticity, Flexural strength and Splitting tensile strength

The results obtained further substantiate the late strength decrease of heat cured concretes. However, the 28-days modulus of elasticity is higher than reference at a W/C = 0.45, decreasing to less than reference at a W/C = 0.35. This could indicate that the modulus of elasticity is less affected by heat curing than the compressive strength at 28 days.

CONCLUDING REMARKS

Heat curing of fly ash/Portland cement concrete catalyses the fly ash reaction in concrete and increases the one-day compressive strength by as much as 40 to 50%. Therefore, fly ash could be a promising supplementary cementitious material for the precast industry. As expected, the later 28-days strength of heat cured concrete is lower than the reference.

Backed by these encouraging results, we recommend to further this investigation to determine the optimum heat curing cycle and define the most appropriate preset time, heat curing temperature and cycle duration. We also recommend to include other sources of fly ash in order to expand the scope of this study to other regions of Canada.

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TABLE 1 PHYSICAL PROPERTIES AND CHEMICAL ANALYSIS OF CSA TYPE 30 (ASTM TYPE 3) CEMENT

DESCRIPTION OF TEST	CSA TYPE 30 CEMENT
Physical tests - general	
Time of set (vicat needle), h:min	1:20
Fineness: 45 μm (passing), %	96.8
Surface area (Blaine), m^2/kg	550
Soundness (autoclave), %	0.03
Physical tests - mortar strength	
Compressive strength of 51 mm cubes, MPa	
1-day	25.0
3-days	35.2
28-days	47.9
Chemical analysis, %	
Insoluble residue	0.6
Silicon dioxide (SiO_2)	20.2
Aluminum oxide (Al_2O_3)	4.8
Ferric oxide (Fe_2O_3)	2.7
Calcium oxide (CaO), total	61.9
Magnesium oxide (MgO)	2.5
Sulphur trioxide (SO_3)	4.3
Loss on ignition	1.9
Other	1.8
Compound composition, %	
Tricalcium silicate (C_3S)	47.5
Dicalcium silicate (C_2S)	20.4
Tricalcium aluminate (C_3A)	9.1
Tetracalcium aluminoferrite (C_4AF)	8.3

TABLE 2 PHYSICAL PROPERTIES AND CHEMICAL ANALYSIS OF THE FLY ASH

DESCRIPTION OF TEST	SPECIFICATION REQUIREMENTS		TEST RESULTS
	ASTM C618-78	CSA 266.3M	
Physical Tests			
Relative density	-	-	2.11
Pozzolanic activity index with Portland cement	min 75	min 75	86
Soundness, autoclave expansion or contraction, %	max 0.5	max 0.5	0.00
Amount retained when wet sieved on 45 μm sieve, max %	max 34	max 34	17.8
Multiple factor (product of L.O.I. and fineness, amount retained when wet sieved on 45 μm sieve), max %	max 225	max 225	7.1
Chemical Tests			
Silicon dioxide (SiO_2) + aluminum oxide (Al_2O_3) + iron oxide (Fe_2O_3), %	min 70.0	-	81.5
Sulphur trioxide (SO_3), %	max 3.0	max 3.0	0.3
Available alkalies as Na_2O, %	max 1.5	max 2.5	2.2
Loss on ignition, %	max 12.0	max 12.0	0.4

TABLE 3 PROJECT OUTLINE

WATER-TO-CEMENT RATIO	0.45				0.40				0.35			
CURING TEMPERATURE (°C) / FLY ASH CONTENT (% BY WEIGHT OF CEMENT)	20[1]	40	55	70	20[1]	40	55	70	20[1]	40	55	70
0	A1	X1	X2	X3	A2	Y1	Y2	Y3	A3	Z1	Z2	Z3
20	B1	X4	X5	X6	B2	Y4	Y5	Y6	B3	Z4	Z5	Z6
30	B4	X7	X8	X9	B5	Y7	Y8	Y9	B6	Z7	Z8	Z9
40	B7	X10	X11	X12	B8	Y10	Y11	Y12	B9	Z10	Z11	Z12

(1) 20°C curing temperature completed in Phase I.

TABLE 4 PROPORTIONS AND PROPERTIES OF FRESH CONCRETE

Mix No.	Mix Proportions, kg/m³					W/C	W/(Cement + Fly Ash)	Superplasticizer % by Cement Weight	Properties of Fresh Concrete			Concrete Dry Density, kg/m³
	CSA Type 30 Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	Total Water				Slump mm	Air, %	Unit Weight, kg/m³	
X1	371	-	820	1030	169	0.46	0.46	-	55	4.4	2390	-
X2	371	-	820	1035	169	0.46	0.46	-	55	4.3	2395	2395
X3	371	-	820	1035	169	0.46	0.46	-	55	4.3	2395	-
X4	370	74	730	1050	167	0.45	0.38	0.26	65	3.9	2395	-
X5	370	74	730	1045	167	0.45	0.38	0.2<	75	4.0	2390	-
X6	370	74	730	1045	167	0.45	0.38	0.26	60	3.9	2390	2400
X7	370	110	680	1045	167	0.45	0.35	0.58	80	3.9	2375	2395
X8	370	110	680	1045	167	0.45	0.35	0.58	80	3.8	2375	-
X9	370	110	680	1050	167	0.45	0.35	0.58	75	3.9	2380	-
X10	366	146	625	1055	165	0.45	0.32	0.39	60	3.8	2360	-
X11	366	146	625	1060	165	0.45	0.32	0.39	60	3.8	2365	2400
X12	366	146	625	1060	165	0.45	0.32	0.39	60	3.8	2365	2390
Y1	375	-	830	1040	152	0.40	0.40	0.94	55	5.0	2400	2435
Y2	375	-	825	1035	152	0.40	0.40	0.94	65	5.4	2390	2420
Y3	375	-	830	1040	152	0.40	0.40	0.94	55	5.0	2400	2445
Y4	376	75	740	1060	152	0.40	0.34	0.78	50	3.8	2405	2445
Y5	375	75	740	1055	152	0.40	0.34	0.78	50	4.0	2400	2445
Y6	376	75	740	1065	152	0.40	0.34	0.78	50	4.0	2410	-

TABLE 4 CONT'D PROPORTIONS AND PROPERTIES OF FRESH CONCRETE

Mix No.	Mix Proportions, kg/m³					W/C	W/(Cement + Fly Ash)	Superplasticizer % by Cement Weight	Properties of Fresh Concrete			Concrete Dry Density, kg/m³
	CSA Type 30 Cement	Fly Ash	Fine Aggregate	Coarse Aggregate	Total Water				Slump mm	Air, %	Unit Weight, kg/m³	
Y7	370	111	680	1050	150	0.41	0.31	1.10	80	4.9	2365	-
Y8	370	111	680	1055	150	0.41	0.31	1.10	80	4.7	2370	-
Y9	370	111	675	1050	150	0.41	0.31	1.10	80	4.9	2360	2410
Y10	370	148	630	1080	151	0.41	0.29	0.92	60	4.5	2380	2420
Y11	370	148	630	1075	151	0.41	0.29	0.97	65	4.2	2375	2425
Y12	370	148	630	1075	151	0.41	0.29	0.97	75	4.3	2375	2415
Z1	379	-	845	1050	135	0.36	0.36	1.41	60	4.8	2410	2450
Z2	383	-	850	1060	137	0.36	0.36	1.41	50	4.3	2430	2475
Z3	378	-	840	1045	135	0.36	0.36	1.41	80	5.4	2400	2445
Z4	377	75	745	1065	135	0.36	0.30	1.59	75	4.7	2400	-
Z5	377	75	745	1070	135	0.36	0.30	1.59	75	4.3	2405	2460
Z6	375	75	740	1060	135	0.36	0.30	1.57	80	4.8	2390	2445
Z7	381	115	705	1090	137	0.36	0.28	1.54	55	3.4	2430	2445
Z8	381	115	705	1090	137	0.36	0.28	1.82	75	4.1	2430	2460
Z9	379	115	695	1080	136	0.36	0.28	1.54	55	3.8	2410	-
Z10	375	150	640	1080	136	0.36	0.26	2.26	80	4.5	2385	2430
Z11	377	151	645	1090	137	0.36	0.26	2.05	80	4.3	2405	-
Z12	375	150	640	1085	136	0.36	0.26	2.15	80	4.4	2390	2435

TABLE 5 NUMBER OF TEST SPECIMENS CAST AND TESTED FROM EACH BATCH

TEST \ BATCH	1	2
No. of cylinders for compression tests at		
1 - day	2	1
7 - days	2	1
28 - days	2	1
No. of cylinders for 28-days splitting tensile test	-	2
No. of cylinders for 28-days modulus of elasticity	1	1
No. of prisms for 14-days flexural test	-	2

TABLE 6 - PROPERTIES OF HARDENED CONCRETE

Mix No.	W/C	Fly Ash, % by wt of cement	Temperature, °C	Properties of Hardened Concrete					
				Compressive strength, MPa			Splitting Tensile Strength, MPa	Flexural Strength, MPa	Modulus of Elasticity, GPa
				1-d	7-d	28-d	28-d	14-d	28-d
X1	0.46	-	40	23.5	28.2	36.2	2.5	4.9	35.3
X2	0.46	-	55	24.7	29.4	36.8	2.7	5.1	34.3
X3	0.46	-	70	25.1	28.5	38.8	2.3	4.9	33.3
X4	0.45	20	40	25.7	30.9	37.9	2.4	6.2	37.2
X5	0.45	20	55	26.0	29.6	37.0	2.6	5.1	36.8
X6	0.45	20	70	28.3	31.4	38.2	2.7	5.4	36.2
X7	0.45	30	40	26.6	32.9	39.7	2.8	6.3	37.5
X8	0.45	30	55	25.6	32.9	39.7	3.2	5.4	37.8
X9	0.45	30	70	34.4	36.2	40.0	2.4	6.0	36.2
X10	0.45	40	40	25.8	32.0	38.4	2.5	6.1	37.5
X11	0.45	40	55	28.9	32.4	36.3	2.4	5.9	36.7
X12	0.45	40	70	34.2	35.7	40.6	2.5	5.8	35.0
Y1	0.40	-	40	29.7	34.6	43.1	3.2	6.1	37.4
Y2	0.40	-	55	31.0	35.0	43.1	2.9	5.5	35.9
Y3	0.40	-	70	31.0	35.5	44.9	2.7	5.3	33.7
Y4	0.40	20	40	29.2	36.0	41.9	2.9	6.1	38.1
Y5	0.40	20	55	31.0	36.0	39.6	2.5	6.9	37.9
Y6	0.40	20	70	34.9	40.7	41.8	2.6	5.8	36.1

TABLE 6 CONT'D PROPERTIES OF HARDENED CONCRETE

Mix No.	W/C	Fly Ash, % by wt of cement	Temperature, °C	Properties of Hardened Concrete					
				Compressive strength, MPa			Splitting Tensile Strength, MPa	Flexural Strength, MPa	Modulus of Elasticity, GPa
				1-d	7-d	28-d	28-d	14-d	28-d
Y7	0.41	30	40	28.0	33.5	40.7	2.6	5.7	37.5
Y8	0.41	30	55	32.2	35.9	40.4	2.4	5.9	35.9
Y9	0.41	30	70	36.1	37.1	40.8	2.8	6.1	36.1
Y10	0.41	40	40	30.9	37.0	41.7	2.6	6.2	38.8
Y11	0.41	40	55	35.3	38.5	44.2	2.2	6.2	36.5
Y12	0.41	40	70	39.4	39.2	43.4	2.3	4.8	35.7
Z1	0.36	-	40	34.0	41.7	47.8	2.8	6.1	38.2
Z2	0.36	-	55	36.6	43.8	51.1	3.1	4.9	37.0
Z3	0.36	-	70	33.4	36.3	47.0	2.3	5.1	35.4
Z4	0.36	20	40	36.5	44.9	53.5	3.1	5.7	39.3
Z5	0.36	20	55	39.9	45.6	53.2	3.0	6.7	38.2
Z6	0.36	20	70	40.7	41.0	49.0	2.6	5.5	36.6
Z7	0.36	30	40	38.8	46.2	53.3	3.0	6.6	39.4
Z8	0.36	30	55	42.3	46.4	50.2	2.2	6.5	39.7
Z9	0.36	30	70	43.8	43.1	48.9	2.5	6.0	37.1
Z10	0.36	40	40	40.1	48.1	55.4	3.2	5.9	39.1
Z11	0.36	40	55	45.4	47.7	52.0	2.9	6.5	40.0
Z12	0.36	40	70	48.9	50.2	52.8	2.6	7.1	38.0

TABLE 7 COMPRESSIVE STRENGTH - f'c , MPa

TIME, DAYS	WATER-TO-CEMENT RATIO	0.45				0.40				0.35			
	TEMPERATURE, °C / FLY ASH, % BY CEMENT WEIGHT	20 (1)	40	55	70	20 (1)	40	55	70	20 (1)	40	55	70
1	0	22.9	23.5	24.7	25.1	29.2	29.7	31.0	31.0	35.0	34.0	36.6	33.4
	20	23.8	25.7	26.0	28.3	28.2	29.2	31.0	34.9	34.9	36.5	39.9	40.7
	30	23.9	26.6	25.6	34.4	28.0	28.0	32.2	36.1	33.5	38.8	42.3	43.8
	40	23.3	25.8	28.9	34.2	27.0	30.9	35.3	39.4	36.0	40.1	45.4	48.9
7	0	32.1	28.2	29.4	28.5	39.1	34.6	35.0	35.5	45.2	41.7	43.8	36.3
	20	33.5	30.9	29.6	31.4	36.6	36.0	36.0	40.7	45.1	44.9	45.6	41.0
	30	33.8	32.9	32.9	36.2	37.5	33.5	35.9	37.1	43.5	46.2	46.4	43.1
	40	33.2	32.0	32.4	35.7	37.3	37.0	38.5	39.2	46.4	48.1	47.7	50.2
28	0	40.3	36.2	36.8	38.8	46.6	43.1	43.1	44.9	54.4	47.8	51.1	47.0
	20	41.2	37.9	37.0	38.2	45.3	41.9	39.6	41.8	54.5	53.5	53.2	49.0
	30	42.6	39.7	39.7	40.0	44.8	40.7	40.4	40.8	52.9	53.3	50.2	48.9
	40	43.6	38.4	36.3	40.6	45.4	41.7	44.2	43.4	57.6	55.4	52.0	52.8

(1) 20°C curing temperature completed in phase 1.

TABLE 8 MODULUS OF ELASTICITY, SPLITTING TENSILE STRENGTH AND FLEXURAL STRENGTH

MECHANICAL PROPERTIES	WATER-TO-CEMENT RATIO	0.45				0.40				0.35			
	TEMPERATURE, °C / FLY ASH % BY CEMENT WEIGHT	20	40	55	70	20	40	55	70	20	40	55	70
28-d Modulus of Elasticity, GPa	0	33.7	35.3	34.3	33.3	36.9	37.4	35.9	33.7	38.4	38.2	37.0	35.4
	20	35.2	37.2	36.8	36.2	37.4	38.1	37.9	36.1	39.6	39.3	39.2	36.6
	30	35.4	37.5	37.8	36.2	38.2	37.5	35.9	36.1	38.1	39.4	39.7	37.1
	40	35.6	37.5	36.7	35.0	36.3	38.8	36.5	35.7	38.8	39.1	40.0	38.0
28-d Splitting Tensile Strength, MPa	0	2.7	2.5	2.7	2.3	3.2	3.2	2.9	2.7	3.5	2.8	3.1	2.3
	20	2.9	2.4	2.6	2.7	3.1	2.9	2.5	2.6	3.4	3.1	3.0	2.6
	30	3.2	2.8	3.2	2.4	3.4	2.6	2.4	2.8	3.8	3.0	2.2	2.5
	40	3.4	2.5	2.4	2.5	3.3	2.6	2.2	2.3	3.9	3.2	2.9	2.6
14-d Flexural Strength, MPa	0	4.9	4.9	5.1	4.9	5.7	6.1	5.5	5.3	6.9	6.1	4.9	5.1
	20	5.0	6.2	5.1	5.4	4.8	6.1	6.9	5.8	6.6	5.7	6.7	5.5
	30	5.5	6.3	5.4	6.0	5.6	5.7	5.9	6.1	6.1	6.6	6.5	6.0
	40	5.2	6.1	5.9	5.8	5.5	6.2	6.2	4.8	7.3	5.9	6.5	7.1

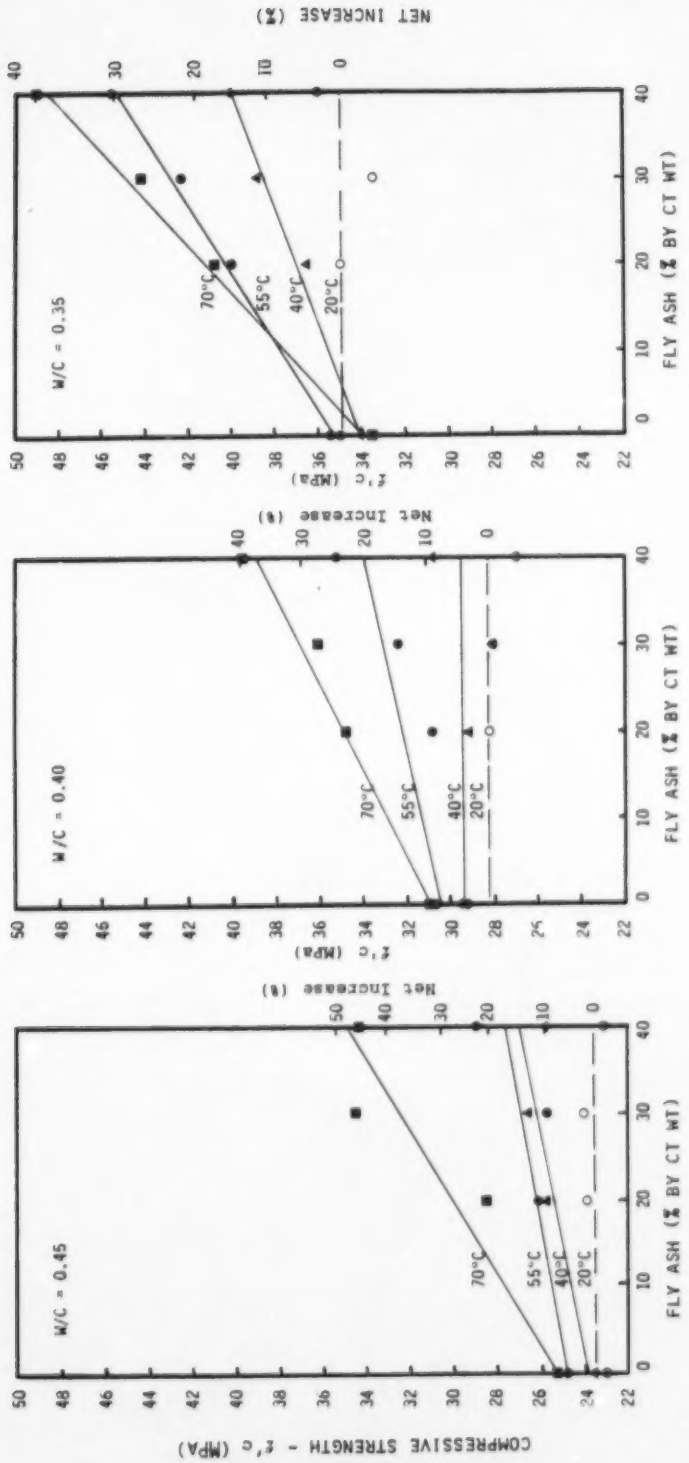

FIGURE 1 ONE-DAY COMPRESSIVE STRENGTH VERSUS THE FLY ASH CONTENT

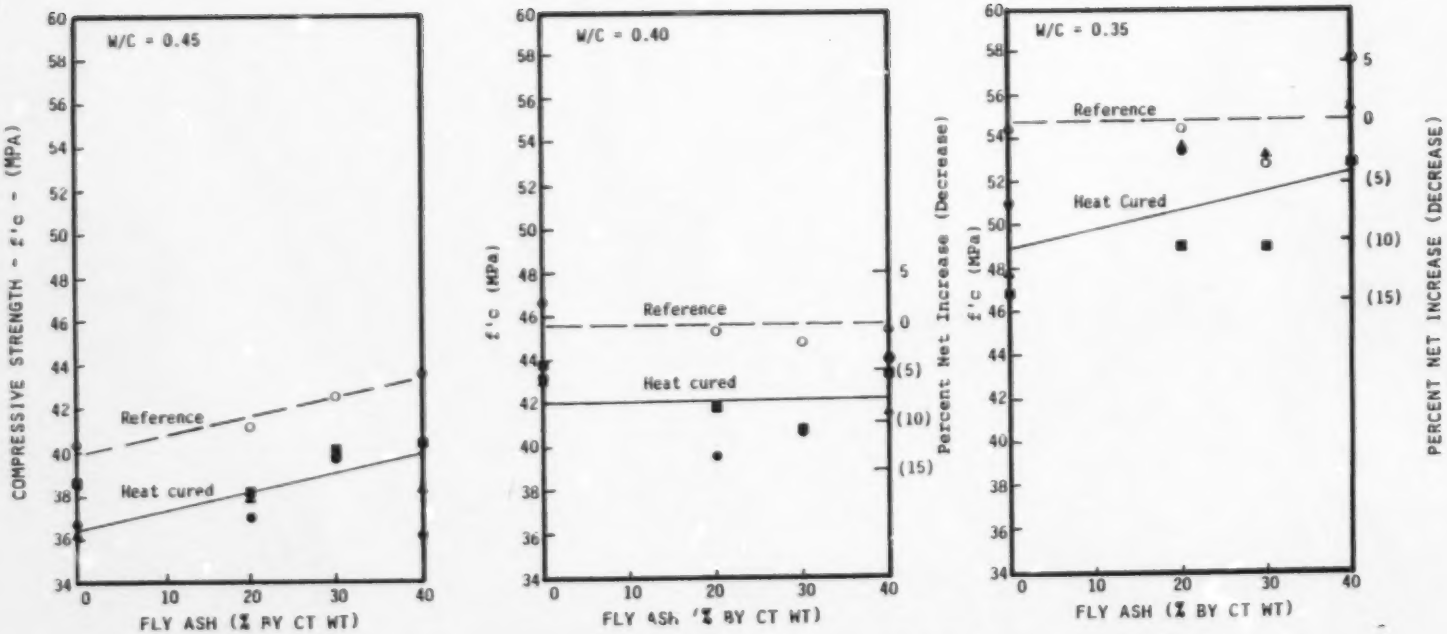

FIGURE 2 28-DAY COMPRESSIVE STRENGTH VERSUS THE FLY ASH CONTENT